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Review on the Current Composting Practices and the Potential of Improvement using Two-Stage Composting

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Composting is one of the applicable technologies to recycle organic waste into a value-added product. It allows the transformation and stabilisation of the organic waste into bio-fertiliser that can be applied to land and crops safely. The composting systems come in different modes but the three commonly used are windrow, aerated static pile and in-vessel composting. The three practices vary in cost, manpower, energy, greenhouse gases emission and composting time. It is well-known that among the three, windrow is the least expensive but most time consuming where in-vessel offers short composting period but at the high expense of energy and cost. Composting is conventionally carried out by either one of the methods. A new strategy, namely the two-stage composting system, is getting popular. It involves the switching of the composting system at different stages of the composting process. Study on the effectiveness and efficiency of two-stage composting systems in terms of cost, time, compost quality and greenhouse gases (GHG) emission are still limited as it is still fairly new. This paper aims to review the existing papers on two-stage composting to provide a better insight on the feasibility and applicability of this strategy as compared to the conventional process flow. This paper also highlights some of the recent achievements in improving the efficacy of the composting system in terms of time and GHG emission.

1. Introduction

Sustainable municipal solid waste (MSW) management is getting more attention these days with the rapid urbanisation and industrialisation, especially in developing country like Malaysia. A significant amount of MSW is generated each day and disposed into a landfill with a recycling and composting rate of less than 5 %. As a cheaper and less complicated technology, composting can be an alternative to landfill in organic waste recycling. The final product, compost, can be used as soil conditional or bio-fertiliser in promoting plant growth. However, the quality of the compost can be varied with the used of different technology and amendments or control system. The application of immature compost can also lead to severe health issues and phytotoxicity to plants.

Composting proceeds in two phases, which are the mineralisation and humification phases (Kulikowska and Gusiatin, 2015). During the mineralisation phase, the organic matter (OM) is degraded mostly by microbial action. During the degradation, C and N transformations are often used to characterise the composting process. Composting is often regarded as a cleaner and greener technology as it represents a biological transformation of the organic waste into nutrient-rich fertiliser. Recent studies have shown composting process can release a significant amount of greenhouse gases (GHG) which has high global warming potential (GWP). The GHG can come from OM decomposition, fossil fuel consumption for machinery and transportation, turning and more (Bong et al., 2017). By just looking at the biological part of the composting process, the type of GHG and the respective GWP released are dependent on several factors: aeration rate and mode, temperature, organic waste, turning frequency, carbon and nitrogen content, pH and more.

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The three common types of composting systems include windrow, aerated static pile and in-vessel. Windrow system is known for its time consumption, usually with a solid retention time of more than 60 d, but it is at the lowest cost. Windrow system has a high demand for land for maturation and curing. In countries with limited land availability, in-vessel composting is attractive as it requires a small amount of land and time. In-vessel is expensive due to its material and energy demand. As in-vessel in an enclosed system, the GHG emission is more likely to be released at the end of the process when the compost is discharged and from the consumption of fossil fuel for energy. In-vessel composting is commonly completed within several days. Two-stage composting is comparatively new. The first paper dealing with two-stage composting was in 2011 (Kulikowska and Klimiuk, 2011) in which two-stage composting is used for the composting of sewage sludge. This configuration involves an alternation between two systems, mostly between windrow and in-vessel. The organic waste spends a short amount of time in the in-vessel system for fast OM degradation than to windrow for continuous degradation and stabilisation. The efficiency and effectiveness of the two-stage composting are yet to be explored. This paper aims to compare the conventional composting process with the two-stage composting in term of the efficiency of the process, the quality of the compost, and the economy and environmental impact of the process.

2. Conventional composting process

The conventional composting process, such as windrow composting, aerated static pile, and in-vessel composting, had been well practised all over the world in past few decades. Significant outcomes of using composting as a sustainable waste management technology had been observed in many types of research and reports. With the increase of awareness of green strategies and green growth, researchers not only focusing on the technology that increases the process efficiency and product quality but also looking at the economic and environmental impacts of the process. This section presents the review of the overall characteristics of each conventional composting process and the respective compost quality, as well as the economy and environmental assessment of each process.

Windrow composting generally refers to the outdoor composting system that strongly relies on mechanical aeration. The organic wastes are mixed and placed into a long and narrow pile and typically turned using a compost turner. It is the least sophisticated among these three systems. And always become the prime candidate when composting is needed to process a high volume of organic wastes. However, windrow composting requires a large area of land and usually taking more time to reach the mature stage.

Aerated static pile (ASP) composting is system involved of forcing (positive) or pulling (negative) ambient air through the compost pile. The pile is created in the way of windrow system but receive little or no mechanical turning. ASP is formally used to compost municipal sewage sludge. A bulking agent such as woodchips usually added to enhance the air flow and adding porosity of the pile. In most case, ASP is used in combination with windrow composting or other systems during the curing phase, with the biomass being degraded into a fine form or being removed via screening.

In-vessel composting involves the confining of the composting process to a variety of containers or vessels. It is available in many systems using a variety of methods to control and accelerate the composting process. Compare to windrow and ASP systems, in-vessel composting is more efficient and less land area is required. Compost production always happens in a very short period of time with the good control of the operational system. In-vessel composting is the most costly system among the rest.

Table 1 and 2 list the characteristics and economy and environmental impacts of each conventional composting system with the basic information extracted from Wei et al. (2001), the environmental and economic details for in-vessel composting extracted from Mu et al. (2017) and windrow composting extracted from Bong et al. (2016), together with other surveys and interviews taken from several composting plant owners. From the economy point of view, windrow system can be a better selection if the land is available, especially when the owner is targeting to compost a large quantity of waste. While from the environmental point of view, windrow composting requires more amendment to be made to reduce its GHG emission. According to Cayuela et al. (2006), turning can result in a higher N loss (~45 %) in windrow as compared to the 10 % N loss in ASP with forced aeration. Higher temperature and longer thermophilic phase are believed to result in a larger N loss. N loss in a form of NH_3 during N volatilisation of NH_4^+ can lead to acidification where N_2O has a high GWP of 310 times that of CO_2 for 100 y timescales. These amendments can be covered or mixed the pile with mature compost (Luo et al., 2014), altered the turning frequency according to temperature changed (Ermolaev et al., 2012), addition of bulking agent (Santos et al., 2015), and sprayed with bamboo vinegar (Chen et al., 2010).

Table 1: Characteristics of each conventional composting system

	Composting System		
	Windrow	ASP	In-Vessel
Preferable waste input	All type of wastes, but preferable for those with less emission of odour such as the plant-based wastes	Preferable for waste with more homogeneity and consistency and bulking agent is required	All type of wastes but preferable for easily degraded wastes such as food waste
Loading capacity	Can accommodate > 10 t of waste. As long as the rise in temperature is observed and maintained for at least 3 d, the functionality of the system is ensured. Usually, the compost pile is more than 1 (Length, L) × 1 (Width, W) × 1 (Height, H) m	Can accommodate > 10 t of waste. As long as the rise in temperature is observed and maintained for at least 3 d, the functionality of the system is ensured. Usually, the compost pile is more than 1 (L) × 1 (W) × 1 (H) m	Usually, can accommodate around 1 – 5 t of waste for the whole composting process
Land area requirement	High	Medium	Low
Site selection and transportation of waste	The site has to be away from populated area, thus higher waste transportation cost	The site has to be away from populated area, thus higher waste transportation cost	The site can be anywhere that can accommodate the composter, and a site nearer to the waste source can be selected
Composting period	Long Faster than passive ASP but slower than active ASP	Long ASP with active airflow will give higher efficiency compare to passive ASP	Short
Type of amendment can be considered	Increase aeration and addition of bulking agent, chemical additive, and microbial additive	Increase airflow in active ASP and addition of bulking agent, chemical additive, and microbial additive	Usually in mechanical aspect, increase the system temperature, pressure, and turning frequency
Composting period (with amendment)	Can be reduced by more than 30 % if amendment successfully applied	Beside increase airflow which might give a similar efficiency than windrow, effect of the rest of the amendments will be lower than windrow system	> 50 % of the time in composting can be reduced, but the curing phase still takes around 4 – 8 weeks.
Compost quality	Medium to good	Medium to good	Good

As listed in Tables 1 and 2, unless there is limited land area and only targeted to compost less amount of waste, in-vessel composting would not be a sustainable choice from the economy point of view. This technology is usually used for on-site composting of household waste in the small community. Fail to manage the system can lead to the production of immature compost. For instance, poor temperature control would release excessive water vapour into the environment and resulted in over-dried compost with minimised biological assimilation. Higher GHG emission can occur with the high electricity consumption. When having a low amount of waste, instead of windrow or ASP, in-vessel must be the priority selection. The using of windrow or ASP for a low amount of waste will result in the failure of the process since the high temperature that required for compost sanitation usually cannot be achieved in this circumstances. The selection of a suitable composting system is necessary when conducting the composting process with the consideration of the waste load, land area available, the waste transportation distance, and economy and environmental impacts. Most importantly the final product quality and safety use of the compost in agricultural land.

Table 2: The economy and environmental impact of conventional composting system

	Composting Windrow	ASP	In-Vessel
Capital cost	Low ✓site construction ✓purchase of turner or tractor and screener ✓setting up of conveyance facilities, screening and baggers	Medium ✓ site construction ✓ purchase of tractor and screener ✓ setting up conveyance facilities, screening, baggers, aeration pipe and blower (for active ASP)	High ✓ purchase of the composter (more composters is required for processing of huge amount of waste) ✓ setting up conveyance facilities, screening and baggers
Management cost	Medium ✓Diesel consumption for turner and tractor ✓relatively high labour cost compare to another system	Low ✓ For active ASP, power or diesel consumption for the air blower ✓ Passive ASP will require less management cost than active ASP	High ✓ Power consumption in operating the composter ✓ Higher maintenance cost for the composter
Labour	High ✓Compost turning ✓Site management	Medium ✓ Site management ✓ System monitoring	Low ✓ Require labour with skill and knowledge in handling the system
Environmental impact	High ✓High GHG emission can occur during the turning process ✓leachate collection and treatment is required to ensure the pollution to a water system	Medium ✓ Lower GHG emission compare to windrow ✓ leachate collection and treatment is required to ensure the pollution to a water system	Medium ✓ No leachate collection is required ✓ The evaporated gases must be collected and filtered before release to the environment ✓ Major GHG emission is associated with the power consumption

3. Two-stage composting

Two-stage system is the composting method that combining two different technologies in a single composting process to improve the final product quality, the efficiency of the process, as well as to reduce the environmental impact of the conventional composting process. It is not a new idea in producing bio-fertiliser. There are several two-stage systems be considered, some of them combining two composting technologies, such as the combination of in-vessel composting and windrow composting or ASP and the combination of vermicomposting and any of the conventional composting; while others might include some mechanical treatment such as pre-treatment of the waste, mechanical biological treatment (BMT) or anaerobic digestion (AD) before composting process. However, in this paper, only the two-stage composting (TSC) process that switching between in-vessel composting, namely primary composting (PC), and a windrow or ASP composting process, namely secondary composting (SC), is reviewed. TSC is a relatively new concept in a two-stage system. Kulikowska and Klimiuk (2011) are the very first researchers that published in this field. They focused on the transformation of OM and the kinetics of the two-stage composting of sewage sludge using rape straw and grass as an amendment. The entire process lasted for 217 d with 10 d of OM degradation and waste sanitation in a bioreactor and 207 d of compost maturation in the windrow. Since the idea of TSC is fairly new, the study on the economy and environmental impacts of TSC are limited. Until now, most of the researches are focused on the improvement of the efficiency of the process and the final product quality. Table 3 lists the recent researches done in TSC and the respective achievements with the applied of different amendments.

In the TSC recorded by Kulikowska and Klimiuk (2011), a constant high temperature of nearly 70 °C was observed in PC. When moving to SC, the temperature dropped from 50 to 30 °C within 40 d. At such mesophilic temperature, there would be less N loss from SC. And since the higher temperature was observed during PC, in the bioreactor, the N loss and GHG emission can be reduced or controlled in minimal range. However, according to Zhang et al. (2013), more thermophilic phases were observed, with one during the PC and another 2 – 4 during the SC. Most of the thermophilic phases observed were > 55 °C. In order to reduce the potential of N loss, bamboo vinegar was added to the compost during SC.

Table 3: Recent achievements in two-stage composting

Reference	Time (d)	Waste	Composting system	Amendment	Remark/ Outcome
(Kulikowska and Klimiuk, 2011)	PC:10 SC:207	Dewatered sewage sludge	• PC: 1 m^3 aerated bioreactor • SC: 0.8 m^3 weekly turned windrow	Different proportion of rape straw and grass	• Process succession is affected by the composition of feedstock • Rape straw increased the compost temperature more. This further improved the humic acid formation.
(Zhang et al., 2013)	PC:6 SC:24	Green waste (fallen leaves and branches)	o PC: non-covered digester (48 (L) × 4 (W) × 2.5 (H) m), automated turning and watering (daily) o SC: windrow (2 (L) × 1.5 (W) × and 1 (H) m), turned and watered every 3 d	Different proportion of brown sugar and calcium superphosphate	o Proposed TSC method able to produce better quality compost in a short period of time o Addition of 0.5 % brown sugar and 6 % calcium superphosphate during SC further improved the quality of compost
(Zhang and Sun, 2014)	PC:6 SC:24	Green waste (fallen leaves and branches)	• PC: non-covered digester (6 (L) × 2 (W) × 1.5 (H) m), automated turning and (daily) • SC: windrow (2 (L) × 1.5 (W) × and 1 (H) m), turned and watered every 3 d	Different proportion of rhamnolipid (RL) and initial compost particle size (IPS)	• Addition of 0.15 % RL and 15 mm IPS particle size enhanced aeration and water permeability, resulted in higher microorganism numbers and enzyme activities thus speeded up the degradation • Mature compost with better quality can be achieve in only 24 d
(Kulikowska and Gusiatin, 2015)	PC:10 SC:170	Dewatered sewage sludge	o PC: 1 m^3 aerated bioreactor o SC: 0.8 m^3 weekly turned windrow	Alteration of the aeration rate in bioreactor (0.5 and 1.0 L/min kg dm)	o Higher aeration rate increased the OM losses in the bioreactor o Low heavy metals concentration, low value of potential ecological risk factor and suitable sanitary quality indicated that compost is safe to use as soil amendment

For all the researches listed in Table 3, the thermophilic temperature range was observed between 55 – 70 °C. This had fulfilled the sanitation of the pile which ensures the safety use of the compost as bio-fertiliser. Zhang and Sun (2014) also showed the reduction in composting time when windrow composting is replaced by TSC. The addition of bulking agent, reduction on the particle size and the alteration of the aeration rate are those crucial factors in affecting the efficiency of the process and the quality of the final product. However, the switching between in-vessel and windrow composting is able to reduce the time, land area and labour required for windrow, as well as the capital cost, power consumption and the composter unit required for in-vessel composting. TSC also reduced the GHG emission and costing from waste transportation if the PC is done on-site to reduce the volume of waste before transport to the site for SC. TSC can be a new approach in managing the household organic waste or market waste. The organic wastes generated can be composted in the digester near the community followed by the transportation of the partly composted wastes from different community to a centralised windrow composting site for further curing.

4. Conclusions

As a conclusion, the newly developed two-stage composting (TSC) that combining in-vessel and windrow composting can be an alternative to replace the conventional composting process in managing the organic wastes. Although detailed analysis of its economy and environmental impact has not been done, it is believed that TSC can reduce the composting time, land area, GHG emission, labour and transportation for windrow composting and the costing, power consumption, and composter unit for in-vessel composting. Better quality of compost can also be produced compared to windrow composting and ASP. However, the detailed analysis of the process and the comparison between conventional composting should be done to ensure the efficiency and effectiveness of TSC in producing bio-fertiliser in the future study.

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